EPRI

technical brief

Pulsed-Ultraviolet Light for Drinking Water Disinfection

Energy Delivery & Utilization Division
Municipal Water and Wastewater Target

Summary

Treating drinking water with ultraviolet (UV) light is new for water utilities in the United States. Although the wastewater treatment industry has used low-pressure UV since the early 1900s, the use of UV systems for surface water treatment is in its infancy. New pulsed-UV systems show considerable promise for inactivating microorganisms while limiting the formation of disinfection by-products (DBPs).

Research work being done by the Metropolitan Water District of Southern California (Metropolitan) is evaluating the effectiveness of pulsed-UV for drinking water treatment. The purposes of this research are to:

- Determine the disinfection effectiveness of pulsed-UV in reducing bacteria, viruses, and protozoan oocysts in drinking water
- Perform a preliminary evaluation of DBPs formed by pulsed-UV disinfection
- Evaluate the potential for UV to control biological fouling on membrane surfaces

As a result of Metropolitan's bench-scale testing of pulsed-UV light, the disinfection effectiveness of its high-intensity, multiple-wavelength (polychromatic) light emission is better understood. In several disinfection challenges, dose-response curves were generated for heterotrophic bacteria, *Cryptosporidium parvum* protozoan oocysts, and MS-2 virus.

To achieve a 99 percent (2-$\log_{10}$) reduction of these organisms, pulsed-UV doses ranging from 7 to 30 millijoules per square centimeter (mJ/cm^2) were needed. These low dosages did not produce adverse levels of DBPs. Furthermore, conventional treatment (coagulation-flocculation/sedimentation/filtration) followed by pulsed-UV disinfection and chloramine addition produced less than 10 µg/L of both trihalomethanes (THMs) and haloacetic acids (HAAs).

Background

Water utilities in California and nationwide are constantly challenged with the problem of balancing effective microbial inactivation (disinfection) with the control of DBPs. Conventional disinfection with chlorine, while effective in inactivating viruses and most pathogenic bacteria, forms chlorinated organic compounds, such as THMs and HAAs, which pose a carcinogenic risk.

Regulated levels of THMs and HAAs are currently 80 and 60 µg/L, respectively, and may be reduced by half within the next 10 years. Thus, water utilities would greatly benefit from a process that effectively inactivates recalcitrant organisms without increasing the risks associated with carcinogenic DBPs. Additionally, the reduced use or elimination of chlorine as a disinfectant lessens the safety risks associated with the transport, storage, and handling of liquid and gaseous chlorine.

Disinfection regulations may require inactivation of *Cryptosporidium parvum* oocysts within the next 5 to 10 years. *Cryptosporidium*, a pathogenic protozoan commonly found in surface waters, has caused waterborne gastrointestinal disease outbreaks, most notably in Milwaukee, Wisconsin where over 400,000 cases were reported. Common disinfectants, such as chlorine and chloramines, do not inactivate *Cryptosporidium* oocysts; however, electrotechnologies such as ozone treatment, pulsed-UV irradiation, and medium-pressure UV hold promise for drinking water disinfection.

Alex Mofidi, Associate Engineer with Metropolitan's Water Quality Process Development Unit, is shown here inserting a sample into the pulsed-UV system.

Technology Overview

UV technology has been used for wastewater disinfection and, in limited applications, for groundwater to inactivate bacteria and viruses. Systems using low-pressure and medium-pressure UV lamps are most commonly used for these applications. In drinking water applications, pulsed-UV irradiation has been identified as a technology that may cost-effectively disinfect pathogenic microorganisms without increasing DBP risks.

List of Acronyms

BOM – Biodegradable Organic Matter

DBPs – Disinfection By-Products. Typically formed with the addition of chemicals such as chlorine to the drinking water. Some DBPs are carcinogenic.

HAAs – Haloacetic acids. A disinfection by-product.

THMs – Trihalomethanes. A disinfection by-product.

Pulsed-UV lamps differ significantly from conventional low- and medium-pressure UV lamps (see Table 1) and produce extremely high light intensities. In pulsed-UV, capacitors build up and deliver electricity in pulses to one or more xenon flash tubes located in the center of a flash chamber, through which water passes. The equipment is designed to provide microsecond duration pulses at 1 to 30 Hertz. With each pulse, the flash tube gives off a high-intensity, broad-band radiation (including germicidal UV radiation), which irradiates the flowing water. Disinfection occurs when the UV light alters the DNA of the microorganisms, thereby preventing reproduction, and, consequently, the transmission of infectious diseases.

Because pulsed-UV light intensities are orders of magnitude higher than low- or medium-pressure UV, the operation and maintenance costs of pulsed-UV may be lower than other technologies.

Medium pressure, continuous-wave UV also shows promise in disinfecting drinking water. Medium-pressure, high-intensity UV emits UV light on a continuous basis as compared to pulsed-UV. Medium-pressure UV lamps emit polychromatic radiation, approximately 20 to 40 percent of which is in the germicidal range. They emit about 10 times the germicidal intensity of the low-pressure lamps used for the disinfection of bacteria and virus, thus fewer lamps are required. Medium-pressure UV systems have been successfully used to disinfect drinking water in Europe and to treat opaque industrial process waters. Recent studies by others have shown that medium-pressure UV has been effective in inactivating *Cryptosporidium* oocysts in drinking water.

Current Status of Research

Bench-scale testing of pulsed-UV light was performed by the staff of Metropolitan. Microorganisms were suspended in water pre-treated by the pre-ozonation, coagulation/flocculation, sedimentation, and biologically active filters. Microorganism suspensions were exposed to pulsed-UV light by insertion into the bench-scale reactor illustrated in Figure 1. Between pulses, the lamp defaults to a standby "simmer" mode.

Heterotrophic bacteria and MS-2 virus were selected as test organisms due to their previous use in UV evaluations and because of their relative ease of quantification. This study also examined the ability of pulsed-UV to disinfect *Cryptosporidium* oocysts as measured by cell-culture infectivity assay. Collectively, these measurements were used to establish the disinfection effectiveness of pulsed-UV compared to other disinfection systems.

Naturally occurring heterotrophic bacteria were effectively disinfected from levels greater than 10,000 colony forming units per milliliter (cfu/mL) to less than 10 cfu/mL with UV doses less than 15 mJ/cm^2. Limited experiments were conducted to determine the potential of repair or regrowth of heterotrophic bacteria after UV irradiation. These experiments were conducted in the presence and absence of both light and chloramines. Test results indicated that the pre-disinfection levels of bacteria were reestablished unless the UV dose was greater than 55 mJ/cm^2, or a secondary disinfectant was present.

Pulsed-UV disinfection reduced MS-2

Table 1. Characteristics of Typical Low-Pressure, Medium-Pressure, and Pulsed-UV Lamps

Characteristic	Low-Pressure	Medium-Pressure	Pulsed-UV
Wavelength	Monochromatic, 85 to 90 percent at 254 nm	Polychromatic, 185 to 1,400 nm	Polychromatic, 185 to 800 nm
Emission	Continuous-wave	Continuous-wave	30 pulses per second
Mercury vapor pressure	10^{-3} to 10^{-2} torr	10^{2} to 10^{4} torr	N/A
Operating temperature	40 to 60°C	500 to 800°C	15,000°C
Arc length	40 to 75 cm	5 to 40 cm	15 cm
Lifetime	8,000 to 10,000 hrs	2,000 to 5,000 hrs	>9,000 hrs @ 30 pulses/sec
Relative light intensity	Low	Medium	High

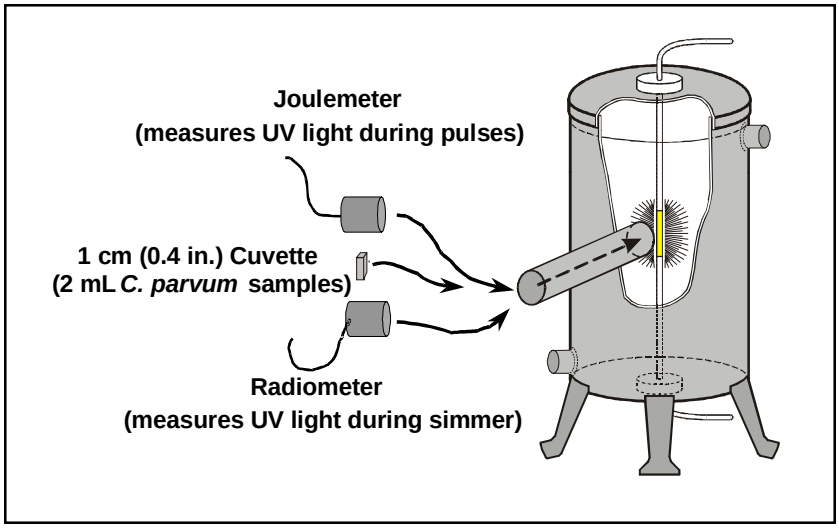

Figure 1. Bench-scale reactor used to test the effectiveness of pulsed-UV light on *Cryptosporidium* oocysts, bacteria, and virus.

virus by more than 6-logs at doses less than 100 mJ/cm^2. Some anomalies occurred in the test results that were attributed to dose measurement variations.

Cryptosporidium tests were conducted with UV doses ranging from 1 to 100 mJ/cm^2. Initial experiments conducted with UV doses between 30 and 100 mJ/cm^2 achieved complete inactivation of *Cryptosporidium* oocysts as measured by cell-culture infectivity. *Cryptosporidium* tests at lower UV doses showed that 2-log reduction could be achieved at a dose of 11 mJ/cm^2.

Measurements of biodegradable organic matter (BOM) and DBPs indicated that localized increases in concentrations occurred in the vicinity of the flash lamp. When blended with water downstream of the lamp, the increases are expected to be insignificant.

An initial estimate of the operating cost for pulsed-UV treatment (8-in diameter pipe, 320 gpm flow rate, and $0.08/kWh electricity cost) was $4.12 per acre-foot ($0.0126/1,000 gallons) of treated water ($0.0033/m^3).

Future Research Activities

Future research activities of this project include investigating the effectiveness of UV in the control of biological fouling of membranes used in water desalination.

Membrane systems used in desalination and softening applications are subject to chemical and biological fouling. Control measures are required to limit the amount of fouling for effective use of the membranes. Membrane fouling may be further impacted when pretreatment includes ozonation followed by biological filtration to remove organic matter. A secondary disinfectant is needed downstream of biological filtration such that high levels of bacteria do not enter the distribution system thereby compromising drinking water quality.

Pulsed-UV following biological filtration and in combination with chloramine addition for regrowth control provides alternative means of disinfection without increasing DBP levels. The pulsed-UV and chloramine dosages needed to prevent bacterial regrowth, however, have not been established. These issues will also be addressed by this research.

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